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(54) Switched reluctance motors

Geschaltete Reluktanzmotoren

Moteurs à réluctance commutée

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Description

This invention relates to a switched reluctance motor comprising a stator defining stator poles each with a pole face, and having a stator winding for energising the stator poles; a rotor defining rotor poles each with a pole face, movement of the rotor being influenced by the stator poles according to the energisation of the stator winding, and a magnetisable member attached to at least one stator or rotor pole, acting as a host pole and positioned such that it influences the rest position of the rotor, when the winding is not energised, to maintain the rotor in a non-zero starting-torque position relative to the stator (see for example WO-A1-90/02437).

A form of switched electric reluctance motor is proposed in patent US 5043618. The motor disclosed in that patent has two poles per pole group, and stator and rotor pole arcs of about 30°. An example is illustrated in Figure 1 of the drawings. Figure 2 illustrates the static torque curve, which is derived from the torque developed by the motor with a constant excitation current in the windings, as a function of the angle θ of rotation of the rotor. Such curves are characteristic of doubly salient pole motors and can be calculated or measured.

Positive torque is assumed to drive the motor in the forward, clockwise, direction so that the angle of rotation θ is increasing positively in Figure 2 in normal operation. At low speed the winding carries current throughout the range of the angle of rotation θ corresponding to the positive torque, from $\theta = -45°$ to $\theta = 0°$.

It will be appreciated with reference to Figure 2 that the motor will only start from rest in the forward direction if the rotor is in a position corresponding to a region of positive torque. On the other hand, if the coil is switched across a d.c. voltage supply when the rotor is in a region corresponding to negative torque, the resulting current in the winding will cause the motor to move in the reverse direction. It will be further appreciated that there are two positions in each torque cycle at which no torque will be developed, e.g. $\theta = 0°$ and $\theta = -45°$ in Figure 2. A rotor angle of $\theta = 0°$ corresponds to a stable condition because if the rotor is displaced from this position in either direction, with current flowing in the winding, the torque will restore the rotor to the initial position. On the other hand, position $\theta = -45°$ corresponds to an unstable position because displacement of the rotor from the position in either direction will cause the rotor to move away from the initial position.

The rotor 1 in Figure 1 is in a stable position of zero torque in relation to the stator 2. Thus, in this position, the motor will fail to start when current is fed to the windings.

In the motor of Figure 3 the rotor is in the unstable position of zero torque with the inter-pole axes of the rotor 1 aligned with the axes of the stator poles.

Thus, there are regions in the rotor cycle in which the above motor will not start and regions in which there will be uncertainty as to at least the initial direction of rotation of the rotor.

US-A-5,117,144 discloses a switched reluctance motor in which the problem of avoiding a zero torque rest position is addressed by arranging permanent magnets between the ferromagnetic stator poles. The permanent magnets influence the rest position of a specially shaped rotor having noses on the rotor poles which come under the influence of the energised ferromagnetic stator poles.

The present invention is characterised in that the magnetisable member forms a lateral extension of the host pole face.

The invention provides for the reliable starting of reluctance motors and is particularly applicable to the motors described in US 5043618. A permanent magnet or magnets may be added to the motor such that when the rotor is at rest, in the absence of current in the stator winding and providing there is not excessive friction or other applied load, the rotor poles will be positioned in relation to the stator poles to ensure rotation when current is supplied to the stator winding. The magnet or magnets are placed at the side of the stator pole or poles in the space between the poles of a pole group and facing the rotor pole across the air gap between them.

Preferably, the magnetisable member is mounted angularly to one side of its host pole. The member may be mounted in a recess in the host pole or on a side face of the host pole.

The particular advantage of this invention in relation to the type of motor described in US 5043618 is that the magnetisable member can be located on the side of a host pole not otherwise occupied by any active material of the motor. Thus, the member can be mounted in a region of substantially no working flux and the operation of the motor is substantially unaffected.

A motor according to the invention may have the same number of poles as that described in US 5043618, but the pole face of one or more of the stator poles is effectively extended circumferentially by a permanent magnet preferably of the same polarity as that produced in the pole by excitation current in the windings. In effect, in the absence of a current, a rotor pole or poles will usually come to rest facing the magnet or magnets. Occasionally the rotor may come to rest with an inter-polar axis of the rotor facing the magnet. In either case a pulse current in the winding will cause the rotor poles to move towards alignment with the stator poles. If as would usually be the case this initial movement is in the normal forward direction, the inertia of the rotor and any connected load will cause the rotor to move past the aligned pole position and thereafter normal switching of the currents under the control of a conventional rotor position sensor will proceed in the well known manner.

If the initial movement is in the reverse direction, the rotor pole will move past the aligned position and current switching under the influence of the rotor position sensor will cause the rotor to reverse its direction of rotation and proceed in the well known manner. In order to ensure starting from any of the possible initial positions, it is simply necessary initially to override the position sensor for a short time when the initial rotor position corresponds to a normally unexcited state. This can easily be implemented, for example, by a logic OR function to which the input signals of the output of the position sensor and a timed pulse initiated by the switch-on command are applied.

The present invention can be put into practice in various ways, some of which will now be described by way of example with reference to the accompanying drawings in which:

Figure 4 is a cross-section of a first embodiment of the invention;
Figure 5 is a torque curve for the magnet of the invention in the embodiment of Figure 4;
Figure 6 is a cross-section according to Figure 4 with the rotor position shifted;
Figures 7 to 11 are scrap-sections of further embodiments of the invention.

Referring to Figure 4, a switched reluctance motor comprises a rotor 10 which is mounted to rotate inside a stator 12. The motor is of the doubly salient type. The rotor has four equiangularly spaced rotor poles 14. Similarly, the stator has four equiangularly spaced stator poles 16 and 16'. The clearance between the faces of the poles on the rotor and the stator as the rotor rotates defines an air gap. The stator poles are excited by a pair of windings 18 to create a pair of adjacent north poles N and a pair of adjacent south poles S according to the motor construction disclosed in US 5043618.

Each one of a pair of opposed stator 16 has a permanent magnet 20,22 mounted on its exposed side opposite that side adjacent its pole winding. The magnet has an orientation which is the same as its host stator pole 16, as seen at the pole face, and effectively forms an extension of the pole face. The longitudinal or axial extent of the magnet may be the same as that for the stator itself or be a proportion of it. In the latter case the magnet may be located toward one axial end of the stator or in a region part way along it.

Figure 5 shows the static torque curve due to each of the permanent magnets 20,22 as a function of the angle of rotation ϑ of the rotor 10. It will be observed that the magnets produce a positive torque in the region around the unstable zero torque position of the static torque curve due to current excitation in Figure 2 and that the magnets produce a negative torque in the region around the stable zero torque position of the stator torque curve due to the current excitation in Figure 2.

Figure 6 shows the motor of Figure 4 with the rotor angularly displaced such that two of the inter-polar axes of the rotor poles are aligned with the axially opposed permanent magnets 20, 22. Figures 4 and 6 show respectively the motor of the present invention with its rotor in the stable and unstable positions of zero torque derived from the permanent magnets as illustrated in the curve of Figure 5.

It will be understood that rotor position sensing means connects the d.c. voltage to the supply over the regions of positive torque of Figure 2 (e.g. $\theta = -45°$ to $\theta = 0°$).

In the absence of current, if the rotor is initially stationary at what would have been a stable position of zero torque in Fig.2 (e.g. $\theta = 0°$), the negative torque produced by the magnets will cause it to move in the reverse direction to the stable zero torque position of Figure 5 (e.g. $\theta = -22½°$). If the rotor is initially stationary at an unstable position of zero torque in Figure 2 (e.g. $\theta = -90°$), the positive torque produced by the magnet will cause it to move in the forward direction to the stable zero torque position in Figure 5 (e.g. $\theta = 22½°$).

While previously if the motor of Figure 1 was switched on with the rotor at rest in any zero torque position for the excitation currents it would fail to start, the magnets extending the pole faces of the present invention prevent it settling in any of these positions. Indeed, it will start particularly well from a position such as $\theta = -22½°$ because of the large positive torque in this region.

More generally, by the same reasoning, the rotor will not remain at rest at any angle other than the stable and unstable zero torque positions of Figure 5 in the absence of any load the magnets themselves are unable to overcome. In the unlikely event that the motor is at rest in an unstable zero torque position (e.g. $\theta = -67½°$), a short pulse of excitation of the winding will impart negative torque to the rotor and cause it to move in the reverse direction to a stable zero torque position e.g. -22½°, or to a region in which the excitation under the control of the rotor position sensing means imparts sufficient positive torque to cause it to reverse its direction of rotation to the forward direction so that normal forward running is established.

As stated above, the motor of Figures 4 and 6 is designed to run in a clockwise direction. If, on the other hand, it is desired that the motor start and run in the anticlockwise direction, this can be achieved by repositioning the magnets 20,22 on the exposed sides of the adjacent poles 16' of like polarity. This will tend to shift the rotor at rest to a non-zero torque position in which the rotor poles are displaced to the opposite side of an adjacent stator pole.

In practice motors designed according to the invention usually develop much greater torques at full current than are developed by the magnets, i.e. the ratio of peak torque in Figures 2 and 5 is usually considerably greater than the relative maximum departures of the respective curves from zero torque indicated. The magnitude and shape of the static torque curve of the magnet can be controlled and designed by the length of the magnets in the longitudinal direction parallel to the axis of the motor, the type of permanent magnet material used and by their radial extent. Only one magnet need be used. However, while any realistic number may be used the use of two is preferred.

The motors are used in applications in which the friction forces and static load forces are significantly lower than the maximum torques produced by the permanent magnets. A fan drive is a typical example of an application to which the motor is well suited.

It will be appreciated in relation to US 5043618 that the region of back of core 24 between poles of a pole group in the modified form carries flux due to the permanent magnets because they are positioned asymmetrically with respect to this part of the magnetic structure. This flux is relatively small and the benefits of reduced lamination material may still be exploited. In fact, the invention is still applicable even when the back of core regions 24 are removed altogether because the flux of the magnets 20 and 22, after crossing the air gap, returns to the stator through the stator poles 16 and 16'.

An important feature of the invention is its simplicity and ease of manufacture. An attractive feature in this respect is that the magnets can be assembled in an unmagnetised state, the magnet being magnetised after assembly by the passage of currents through the stator windings. Alternatively, electro-magnets magnetisable by means of an auxiliary winding may be used in place of permanent magnets. In this case the magnet core material need not be permanently magnetised. The excitation of the magnetisable member may be under the control of a motor control circuit having an auxiliary program operable simply to excite the member to urge the rotor out of an undesirable position only for starting and then to de-energise the member while the motor is running or not in use.

Figure 7 shows a stator pole magnet 28 mounted in a recess 30 in the pole 32 itself. The pole face is arcuate, but the surface of the starting magnet facing the rotor pole path is flat. In Figure 8 a magnet 34 is again mounted on the side of the host stator pole 16. However, the surface of the magnet facing the rotor pole path is arcuate, having the same radius of arc as the stator pole face and defining the same air gap as the host stator pole face with respect to the rotor pole face. The arcuate face on the starting magnet allows it to maintain its optimum closeness to the periphery of the rotor pole path. Because of this the starting force exerted by the magnet is greater over a wider arc than for a magnet of equal strength but with a flat facing surface.

Figure 9 illustrates a magnet 36 in a recess 38 in the stator pole 32. The magnet is angularly spaced from the pole face by a non-magnetic spacing piece 40. An example of a spacing piece would be some glue to hold the magnet in place causing the spacing, or an adhesive pad having the same function.

In Figure 10 a magnet 42 is located behind an arcuate section non-magnetic cover plate 44. The plate 44 extends between the edges on the exposed side of adjacent stator poles 16. Together with the arcuate pole faces the cover plate presents a smooth circular surface to the rotating rotor when such plates are fitted between all adjacent poles. This is aerodynamically advantageous and serves to reduce the wind noise and windage losses in the motor. Because the plate 44 is non-magnetic it is magnetically indistinguishable from the air gap in terms of its reluctance to the flow of flux.

In Figure 11 a magnet 46 is shown on a stator 48 in which a winding 50 embraces a single pole 52 as described in US 5043618. The magnet 46 is mounted in a recess 54 in the host stator pole similar to the arrangement in Figure 7.

It will be appreciated that one or more magnets according to the invention can be fitted to a motor. Where there are more than two poles in a group of poles a selection or all of the poles in the group may be fitted with a magnet, e.g. two starting magnets can be fitted on two poles in a group of three. Differing arrangements of magnet can also be used on the same motor.

The magnetisable member may equally well be attached to a rotor pole. However, because the rotor is rotating at speed careful consideration must be given to balancing it and to attaching it securely to the host rotor pole.

It will also be appreciated that the motor according to the invention can be run as a generator.

Claims

1. A switched reluctance motor comprising:

    a stator (12) defining stator poles (16;16') each with a pole face, and having a stator winding (18) for energising the stator poles;
    a rotor (10) defining rotor poles (14) each with a pole face, movement of the rotor being influenced by the stator poles according to the energisation of the stator winding; and
    a magnetisable member (20) attached to at least one stator or rotor pole, acting as a host pole and positioned such that it influences the rest position of the rotor, when the winding is not energised, to maintain the rotor in a non-zero starting-torque position relative to the stator; characterised in that:
    the magnetisable member forms a lateral extension of the host pole face.

2. A motor as claimed in claim 1 in which the magnetisable member is a permanent magnet (20) or an electromagnet.

3. A motor as claimed in claim 1 or 2 in which the magnetisable member is mounted angularly to one side of its host pole.

4. A motor as claimed in claim 3 in which the stator poles of like magnetic orientation are grouped together and the magnetic orientation of adjacent

groups is different, at least one group of stator poles of like orientation having at least one magnetisable member for influencing the rotor.

5. A motor as claimed in any of claims 1 to 4 in which the magnetisable member is mounted in a recess in the pole face.

6. A motor as claimed in any of claims 1 to 4 in which the magnetisable member is mounted on a side face of the host pole.

7. A motor as claimed in any of claims 1 to 6 in which the end face of the magnetisable member is flat or arcuate with respect to the axis of rotation of the rotor.

8. A motor as claimed in any of claims 1 to 7 in which a non-magnetic cover plate (44) spans the angularly extending gaps between the poles of the stator to present a substantially smooth circular section surface to the rotor.

9. A motor as claimed in any of claims 1 to 8 in which the polarity of the magnet is orientated to be the same as that at its host pole when energised.

Patentansprüche

1. Geschalteter Reluktanzmotor, welcher umfaßt: einen Stator (12), der Statorpole (16, 16') bildet, von denen jeder eine Polschuhfläche aufweist, und der eine Statorwicklung (18) zur Erregung der Statorpole besitzt; einen Rotor (10), der Rotorpole (14) bildet, von denen jeder eine Polschuhfläche aufweist,wobei die Bewegung des Rotors durch die Statorpole entsprechend der Erregung der Statorwicklung bestimmt wird; und ein magnetisieibares Teil (20), das an mindestens einem als Hostpol fungierenden Stator- oder Rotorpol befestigt ist, und welches so angeordnet ist, daß es die Ruheposition des Rotors beeinflußt, wenn die Wicklung nicht erregt wird, um den Rotor in einer relativ zum Stator von Null abweichenden, verdrehten Startposition zu halten; **dadurch gekennzeichnet,** daß das magnetisierbare Teil eine Verlängerung des Hostpolschuhs bildet.

2. Motor nach Anspruch 1, **dadurch gekennzeichnet,** daß das magnetisierbare Teil ein Permanentmagnet (20) oder ein Elektromagnet ist.

3. Motor nach Anspruch 1 oder 2, **dadurch gekennzeichnet,** daß das magnetisierbare Teil abgewinkelt an einer Seite seines Hostpols befestigt ist.

4. Motor nach Anspruch 3, **dadurch gekennzeichnet,** daß die Statorpole gleicher magnetischer Richtung Gruppen bilden, daß die magnetische Richtung nebeneinanderliegender Gruppen unterschiedlich ist, und daß mindestens eine Gruppe der Statorpole gleicher Richtung mindestens ein magnetisierbares Teil zur Beeinflussung des Rotors aufweist.

5. Motor nach einem oder mehreiren der vorhergehenden Ansprüche, **dadurch gekennzeichnet,** daß das magnetisierbare Teil in einer Ausnehmung in der Polschuhfläche befestigt ist.

6. Motor nach einem oder mehreren der Anspruche 1 bis 4, **dadurch gekennzeichnet,** daß das magnetisierbare Teil an einer Seitenfläche des Hostpols befestigt ist.

7. Motor nach einem oder mehreren der Ansprüche 1 bis 6, **dadurch gekennzeichnet,** daß die Endfläche des magnetisierbaren Teils in bezug auf die Rotationsachse des Rotors flach oder gekrümmt ist.

8. Motor nach einem oder mehreren der Ansprüche 1 bis 7, **dadurch gekennzeichnet,** daß eine nichtmagnetische Deckplatte (44) die im Winkel vorhandenden Lücken zwischen den Polen des Stators überspannt, um eine im wesentlichen glatte Kreisabschnittsfläche gegenüber dem Rotor zu bilden.

9. Motor nach einem oder mehreren der vorhergehenden Ansprüche, **dadurch gekennzeichnet,** daß die Polarität, des Magneten so gerichtet ist, daß sie bei Erregung gleich der seines Hostpols ist.

Revendications

1. Moteur à reluctance commutée comprenant :

un stator (12) définissant des pôles de stator (16;16') possédant chacun une face polaire, et comportant un enroulement statorique (18) pour exciter les pôles du stator;
un rotor (10) définissant des pôles de rotor (14) possédant chacun une face polaire, le déplacement du rotor étant influencé par les pôles statoriques en fonction de l'excitation de l'enroulement statorique; et
l'élément aimantable (20) fixé à au moins à un pôle du stator ou du rotor agissant en tant que pôle principal et étant positionné de telle sorte qu'il influe sur la position de repos du rotor, lorsque l'enroulement n'est pas excité, de manière à maintenir le rotor dans une position de couple au démarrage nul par rapport au stator; caractérisé en ce que :
l'élément aimantable forme un prolongement

latéral de la face du pôle principal.

2. Moteur selon la revendication 1, dans lequel l'aimant aimantable est un aimant permanent (20) ou un électroaimant.

3. Moteur selon la revendication 1 ou 2, dans lequel l'élément aimantable est monté angulairement d'un côté de son pôle principal.

4. Moteur selon la revendication 3, dans lequel les pôles du stator ayant une même orientation magnétique sont regroupés et l'orientation magnétique de groupes adjacents est différente, au moins un groupe de pôles du stator ayant une même orientation comportant au moins un élément aimantable servant à influer sur le rotor.

5. Moteur selon l'une quelconque des revendications 1 à 4, dans lequel l'élément aimantable est monté dans un renfoncement situé dans la face polaire.

6. Moteur selon l'une quelconque des revendications 1 à 4, dans lequel l'élément aimantable est monté sur une face latérale du pôle principal.

7. Moteur selon l'une quelconque des revendications 1 à 6, dans lequel la face d'extrémité de l'élément aimantable est plate ou courbe par rapport à l'axe de rotation du rotor.

8. Moteur selon l'une quelconque des revendications 1 à 7, dans lequel une plaque de revêtement amagnétique (44) comble les interstices qui s'étendent angulairement entre les pôles du stator de manière à présenter au rotor une surface de section circulaire essentiellement lisse.

9. Moteur selon l'une quelconque des revendications 1 à 8, dans lequel la polarité d'éléments est orientée de manière à être la même que celle présente au niveau de son pôle principal lorsqu'il est excité.

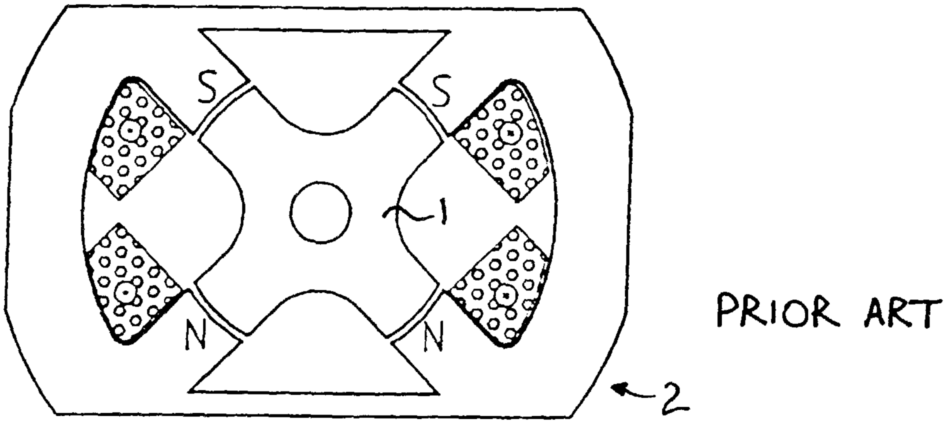


Fig. 1

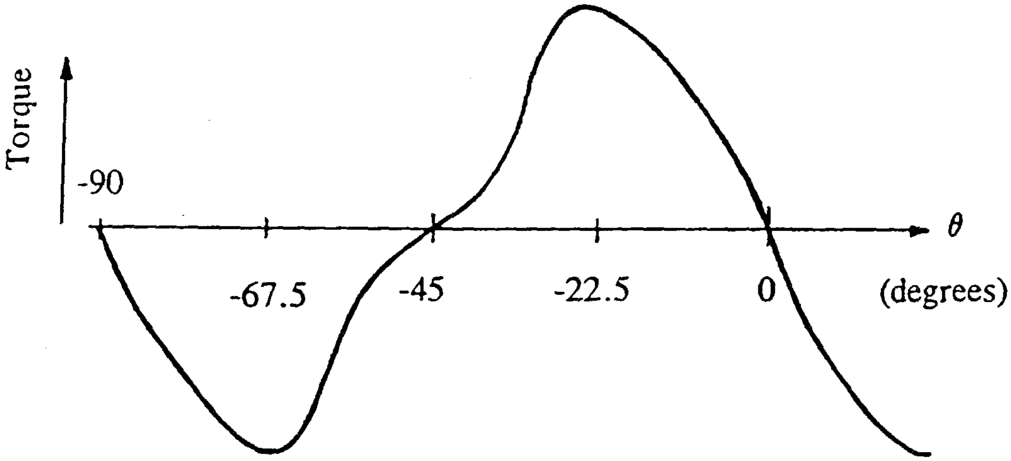


Fig. 2

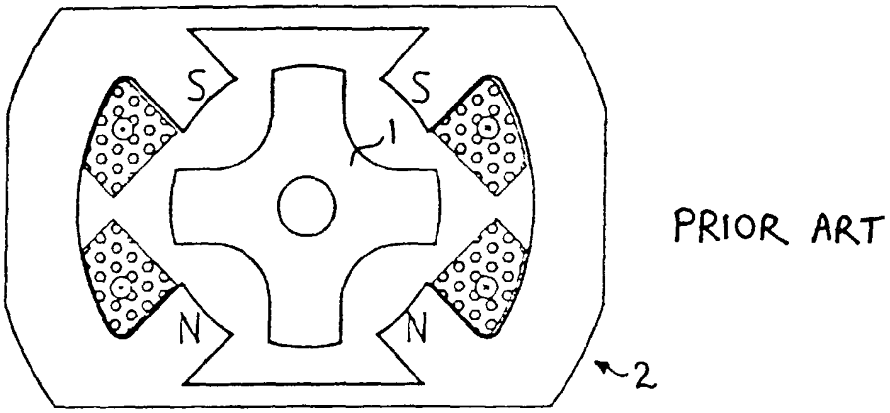


Fig. 3

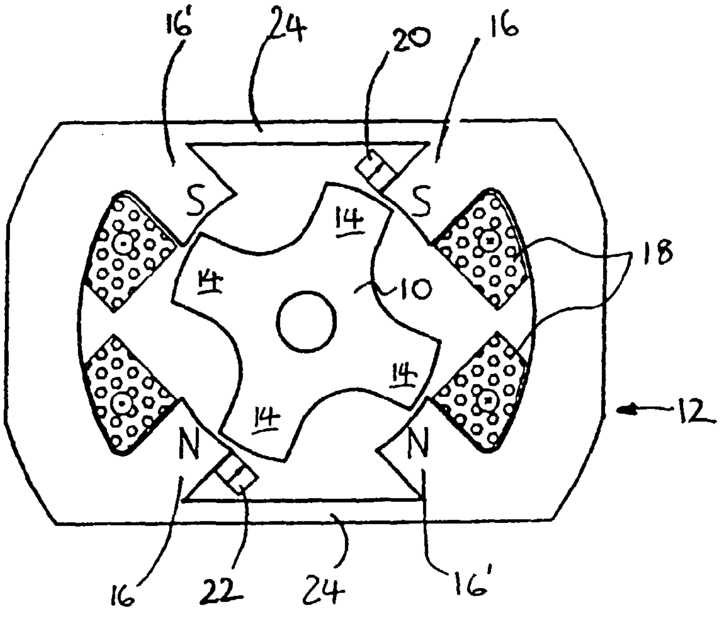


Fig. 4

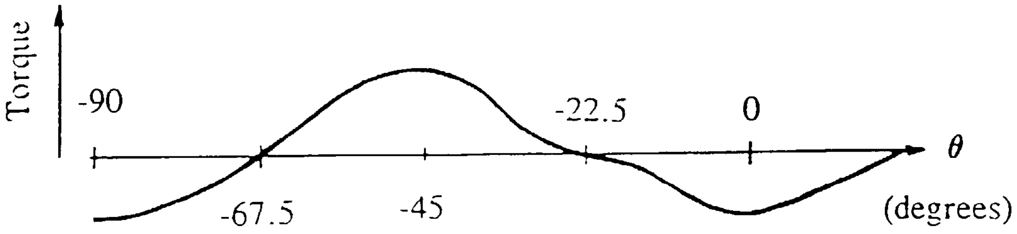

Torque
-90
-67.5
-45
-22.5
0
θ
(degrees)

Fig. 5

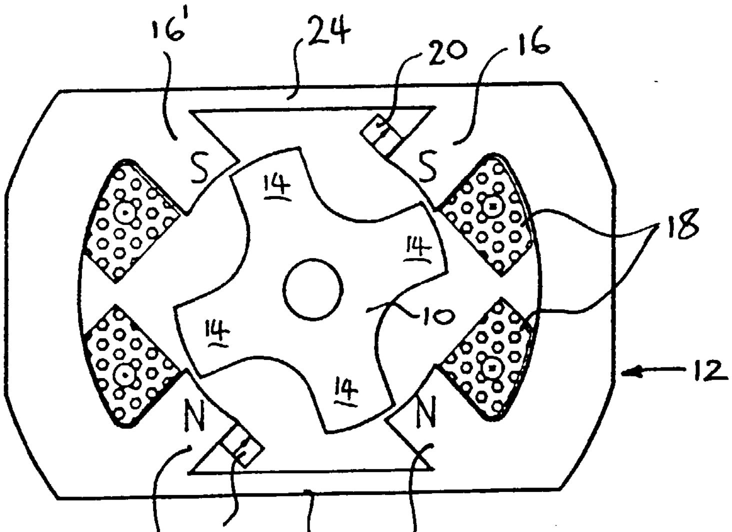

16'
24
20
16
S
S
14
14
14
14
10
18
12
N
N
16
22
24
16'

Fig. 6

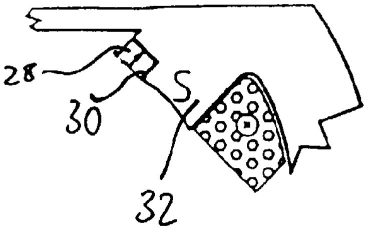


Fig. 7

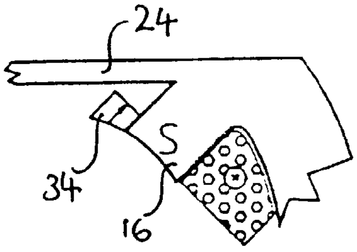
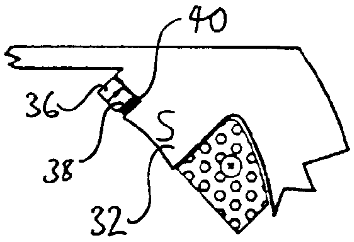


Fig. 8

Fig. 9



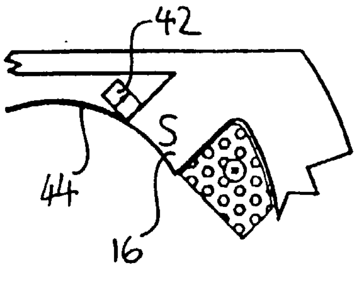


Fig. 10

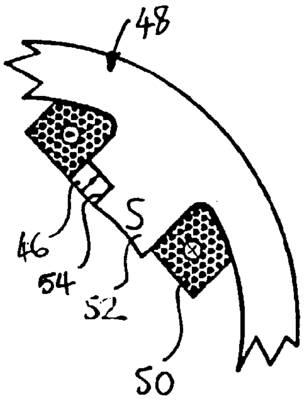


Fig. 11